Recent Progress with the JWST Observatory

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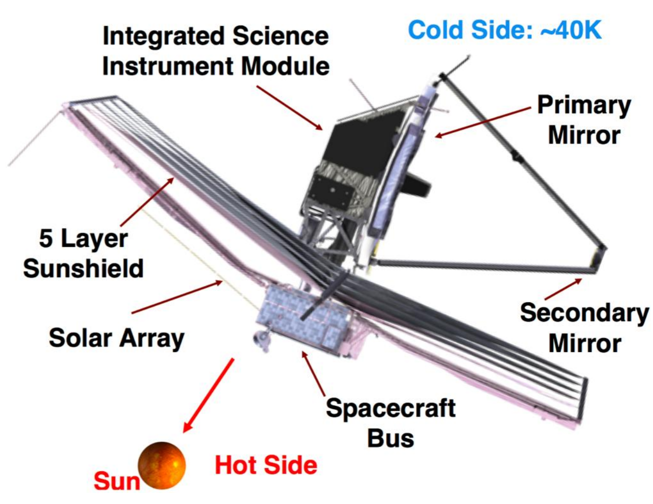
Abstract

The James Webb Space Telescope (JWST) is a large aperture (6.5 meter), cryogenic space telescope with a suite of near and mid-infrared instruments covering the wavelength range of 0.6 µm - 28 µm. JWST's primary science goal is to detect and characterize the first galaxies. It will also study the assembly of galaxies, star formation, and the formation of evolution of planetary systems. JWST is a segmented mirror telescope operating at ~40K, a temperature achieved by passive cooling of the observatory, via a large, 5-layer membrane-based sunshield. We present an overview of the observatory systems design, the science instruments and the mission science objectives. With the completion of the Spacecraft Critical Design Review, the spacecraft has also fully transitioned to fabrication. We will discuss recent highlights associated with the Observatory, including completion and delivery of the primary mirror segments, delivery of the primary mirror backplane and its wings, and the delivery of five template membrane layers. We will also summarize the current predicted performance of the telescope, including stray light, pointing and image quality following the completion of the final design review. Finally, the current schedule through to launch will be presented with a summary of integration and test activities planned when the science payload is delivered to Northrop Grumman following cryo-optical testing at the Johns Space Flight Center.

1. Introduction

The James Webb Space Telescope (JWST) is a 6.5 meter aperture, cryogenic space telescope that will launch in 2018. JWST is designed to undertake a broad range of science programs (Gardner et al. 2006) covering the major themes: *First light and re-ionization*, which seeks to identify the first galaxies to form in the universe, and trace the ionization history of the universe; the *Assembly of Galaxie*s which will determine how galaxies and dark matter evolved to the present day; the *Birth of Stars and Protoplanetary Systems which* will study how stars are formed, and focus on the early development of stars and the formation of protoplanetary systems; and *Planetary Systems and the Origins of Life which* will focus on the physical and chemical properties of our own solar system and exosolar planetary systems. JWST is the natural successor to the UV/Visible/Near-IR Hubble Space Telescope (HST), and the mid to far-infrared Spitzer Space Telescope (SST). JWST will build on the scientific legacy of these missions and provide a factor of 10 - 100 increase in discovery space when compared to Spitzer and HST.

Figure 1: The design and operating concept of the James Webb Space Telescope



2. JWST's Architecture

JWST's design is primarily driven by the goal of detecting extremely faint objects in the early universe. To achieve high sensitivity, JWST combines a large aperture with 25 m^2 collecting area, diffraction-limited imaging in the near-IR (Strehl=0.8 at 2 µm), and cryogenic operating temperatures (~40 K) to facilitate zodi-limited, near and mid-infrared imaging (1 µm - 10 µm). JWST is designed as an observatory facility to operate for 5 years, with a goal of 10 years. This requirement precludes the use of life-limiting cryogens, so JWST employs an innovative, passive cooling architecture based on a five-layer, membrane sunshield, where each layer is approximately the size of a tennis court.

Space Telescopes and Instrumentation 2014: Optical, Infrared, and Millimeter Wave, edited by Jacobus M. Oschmann, Jr., Mark Clampin, Giovanni G. Fazio, Howard A. MacEwen, Proc. of SPIE Vol. 9143, 914302 · © 2014 SPIE
CCC code: 0277-786X/14/$18 · doi: 10.1117/12.2057537

JWST will operate from an orbit around the second Lagrange point (L2). The propellant required to maintain station around L2, and periodically unload accumulated momentum in the reaction wheels is the primary limitation on mission lifetime.

Figure 2: JWST shown in its stowed launch configuration in the fairing of an Ariane 5.

The James Webb Space Telescope (JWST) is shown schematically in Figure 1. The observatory design comprises three major elements, the spacecraft bus, the optical telescope element (OTE) and the Integrated Science Instrument Module (ISIM), and the sunshield. The spacecraft bus is located on the hot side of the observatory that faces the sun. The optical telescope element (OTE), and the Integrated Science Instrument Module (ISIM) that houses the science instruments, avionics and radiator panels are located on the cold side in the shadow of the sunshield. The 5-layer sunshield serves as the interface between the two thermal zones. The cold side hardware interfaces to the spacecraft bus, the primary hot-side hardware element, via a tower structure that is deployed after launch to lift the telescope off the spacecraft bus. The spacecraft bus is built around the observatory's main structural member, a composite cone that houses the propulsion tanks and thrusters. The spacecraft bus also serves as the mounting point for a single, deployable solar array.

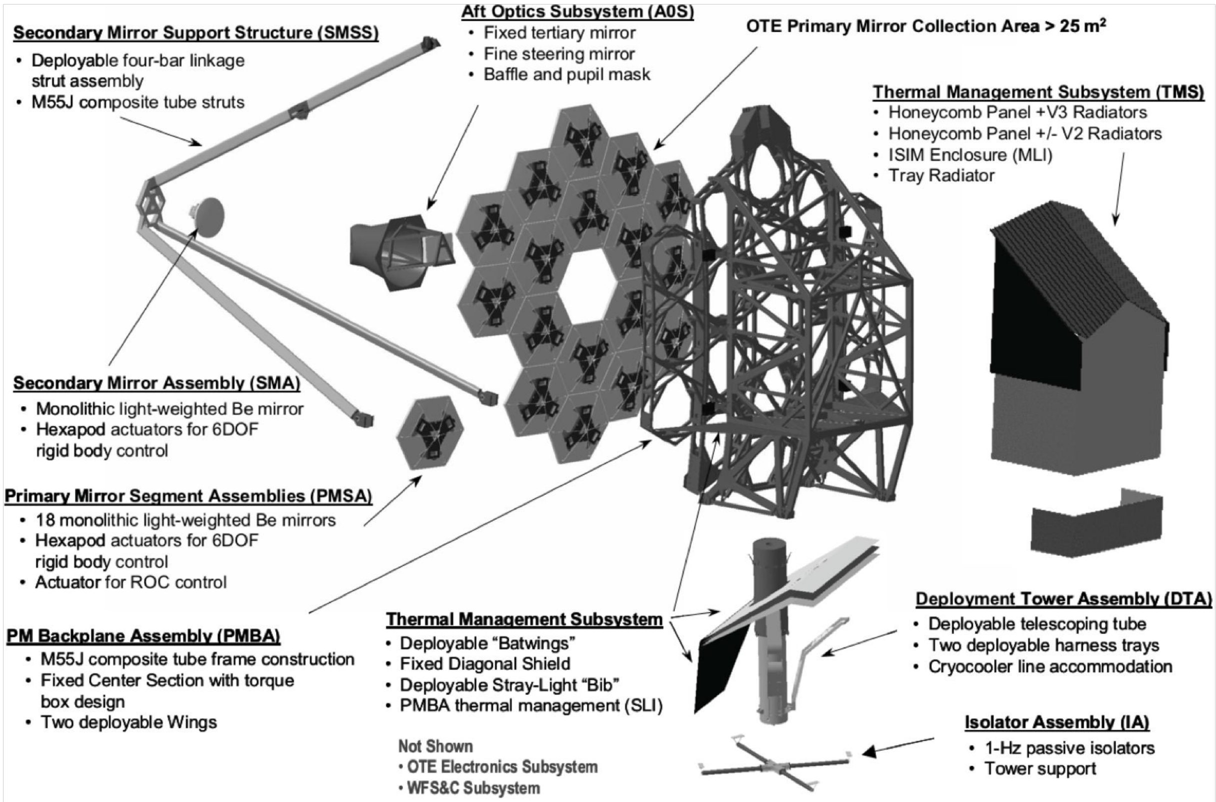
A significant challenge for JWST is the launch envelope imposed by the Ariane 5 fairing. The observatory has to be stowed for launch, and subsequently deployed on the way to its final orbit. The stowed launch configuration is shown in Figure 2, and is facilitated by the segmented mirror architecture that permits the primary mirror to be folded into three parts for launch. The telescope's optical sub-systems are mounted to the backbone of JWST, the primary mirror backplane assembly (PMBA). Installed in the rear of the PMBA is the ISIM, which mounts the four science instruments and their flight avionics. The sunshield comprises five kapton membranes that are folded onto a fore and aft pallet for launch. The sunshield layers are coated with vacuum deposited aluminum, except the layer facing the sun, which is coated with a proprietary silicon-based coating. The sunshield pallets fold up and stow around the telescope for launch. The JWST observatory is launched into orbit around the second Lagrange point L2 via direct insertion. Science operations in this orbit can be conducted 24 hours per day, maximizing the efficiency of scientific observations. The L2 orbit also presents a very benign thermal environment, helping to make JWST a very stable observatory.

3. Optical Telescope Element (OTE)

The major subsystems that comprise JWST's telescope as known as the Optical Telescope Element **(OTE)** and are shown schematically in Figure 3. JWST employs a three-mirror anastigmat delivering a large, corrected field of view. A fourth flat mirror, the Fine steering mirror (FSM) is actively controlled and provides image stabilization utilizing guidance signals provided by the Fine Guidance Sensor (FGS) instrument. The telescope optics are fabricated from beryllium, which was selected for its light weight, stiffness and thermal stability. The primary mirror is constructed from 18 hexagonal mirror segments, mounted on actuators to provide six degrees of freedom. A seventh actuator allows the focus of each segment to be adjusted so that all mirrors are confocal. The secondary mirror is installed on a support structure that can fold and be stowed for launch. The secondary mirror is also mounted on actuators to provide six degrees of freedom. The primary mirror and secondary mirror support structure are both mounted to a composite structure known as the primary mirror backplane assembly (PMBA) that locates the mirrors in relative alignment, with each other and with respect to the science instruments. The PMBA comprises a center section, two hinged wings, and the backplane support fixture, which mounts the ISIM with its four science instruments.. The wings fold alongside the ISIM when stowed for launch, and each wing supports three primary mirror segments. The wings rotate and lock into place during post-launch deployment of the OTE.

All of the beryllium mirrors for JWST's telescope have been completed and delivered to the Goddard Space Flight Center (GSFC), where they are being stored ready for OTE integration. Fabrication, polishing and coating of the mirrors was completed in late 2011 and described by Feinberg et al. (2012). The measured cryogenic surface figures for each of the mirrors are shown in Figure 4, and demonstrate that the mirrors meet their requirements. Simulated images based on results from the mirror's cryogenic acceptance test program show that the optical performance the mirrors are predicted

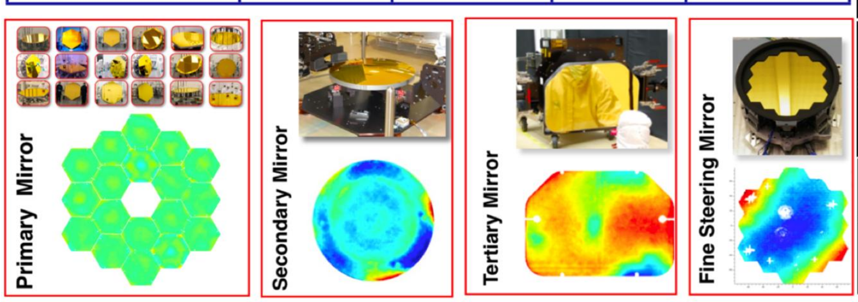
Figure 3: Schematic showing the primary components of the Optical Telescope Element

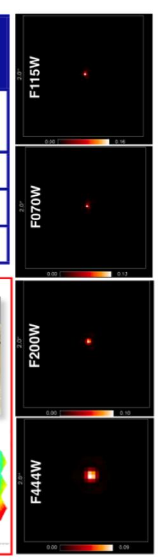


to deliver is diffraction limited imaging at wavelengths 2 µm. The image quality at shorter wavelengths, while not fully diffraction-limited will permit a wide range of science programs, such as stellar populations, to be undertaken at wavelengths down to the mirror's reflectivity cutoff at ~600 nm. JWST's flight mirrors have all received a gold coating to maximize their reflectivity in the infrared (Keski-Kuha et al. 2012). The measured reflectivity for the four mirror optical chain exceeds requirements at every wavelength (e.g. ~93% at 2.5 µm).

Figure 4: Measured surface figure errors are shown with images of the each mirror's cryogenic surface figure error, and their acceptance test results. On the right we show simulated 2" x 2" image boxes, based on initial surface figure measurements from cryogenic testing of the mirror segment A4 (Bowers et al. 2012).

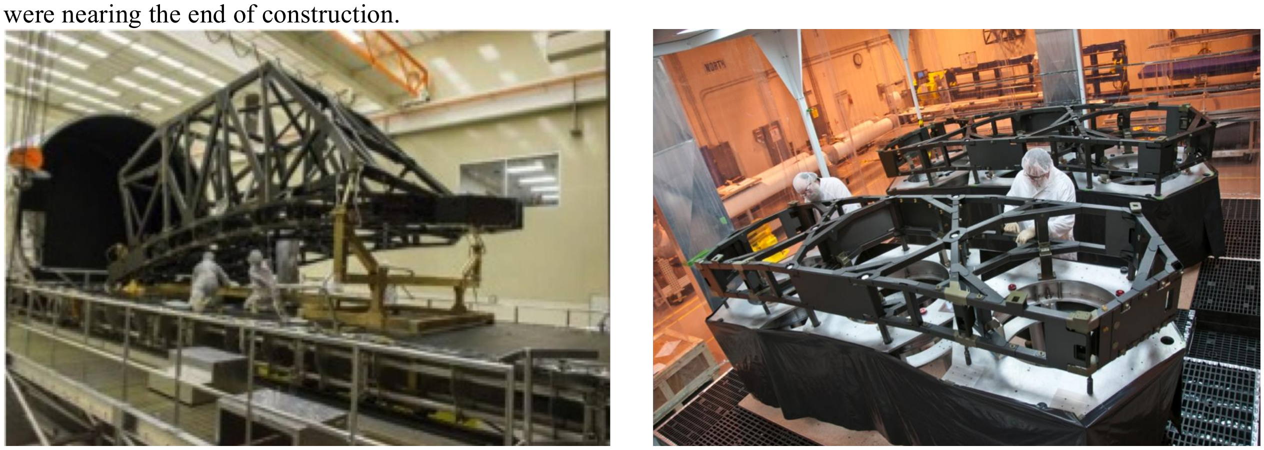
Mirror	Measured (RMS SFE)	Uncertainty (RMS SFE)	Total (RMS SFE)	Requirement (RMS SFE)
18 primary Segments (Composite Figure)	23.6	8.1	25.0	25.8
Secondary	14.7	13.2	19.8	23.5
Tertiary	18.1	9.5	20.5	23.2
FSM	13.9	4.9	14.7	18.7





The primary mirror backplane (see Figure 3) is also making excellent progress. Construction of the center section, the two wings, and the backplane support fixture (BSF) is complete. The center section and BSF have been mated, as is shown in Figure 5. Each composite structure has also completed cryo-cycling at the X-Ray Calibration Facility (XRCF) where the structures were each tested to the required minimum cryogenic temperature, and optical interface metrology collected at the flight operating temperature. Currently, the PMBA elements are undergoing static loads testing. Following completion of these tests and integration of the wings with the center section, the structure will be delivered to GSFC for the start of mirror integration in early 2015.

Figure 5: The PMBA center section and backplane support fixture shown on the left being installed in the X-ray Calibration Facility at the Marshall Space Flight Center for cryogenic testing. The wings are shown on the right as they were nearing the end of construction.



In addition to the flight PMBA center section, a second partial backplane structure, known as the pathfinder has been completed. It is integrated with secondary mirror support struts and a secondary mirror mount and will be delivered to GSFC in July 2014. The pathfinder will continue the JWST's program of early checkouts of key hardware and test procedures using flight-like hardware. The pathfinder will be populated with two flight spare primary mirror segments, and the flight spare secondary mirror. It will then be shipped to the Johnson Space Center (JSC), where it will be employed to check out the equipment and test procedures to be employed during the flight cryo-optical end-to-end test in Chamber-A cryogenic test facility. The pathfinder is shown in Figure 5, during powered deployment testing of the secondary mirror structure.

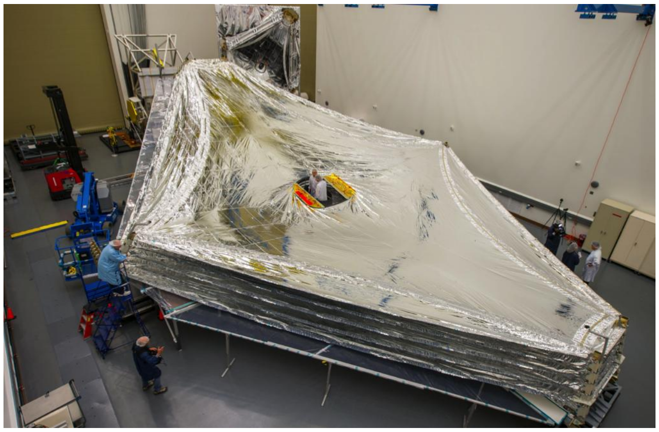
Figure 6: The pathfinder comprises a spare PMBA center section and secondary mirror support structure. I t is shown here demonstrating a powered deployment at Northrop Grumman.

4. Sunshield

JWST's sunshield membranes have reached completion of their development with the production of template membrane layers that are designed to be similar to the final flight membranes. Five template membranes have been manufactured at Mantech-Nexolve (Huntsville). These template membranes are being used to verify finite element models that predict membrane shape and alignment tolerances once they are tensioned with their catenary cables. In order to determine the 3-D shape of these tensioned membranes, the surface of each template membrane was measured with Lidar. The 3-D shape is important since the membranes have to deploy with the required spacing between layers, and their edges have to meet critical alignment requirements, in order that the telescope optics do not have a view to the warmer sunshield layers which would compromise infrared sensitivity of the telescope.

The template membranes are now installed on Northrop Grumman's Independent Test Article (IVA), a full-scale mockup of JWST's sunshield deployment hardware. Just recently, full-scale deployment tests to demonstrate the sequence of sunshield deployments, including membrane separation and tensioning, have begin. Figure 7 shows the fully deployed five layer sunshield following the first successful end-to-end membrane deployment on the IVA. These tests will grow in complexity as more flight-like hardware is added to IVA and allow the deployment sequence to be optimized as well as allowing potential snags and envelope violations to identified and mitigated.

Figure 7: The 5-layer sunshield following successful deployment and tensioning of the five template membranes on the IVA.



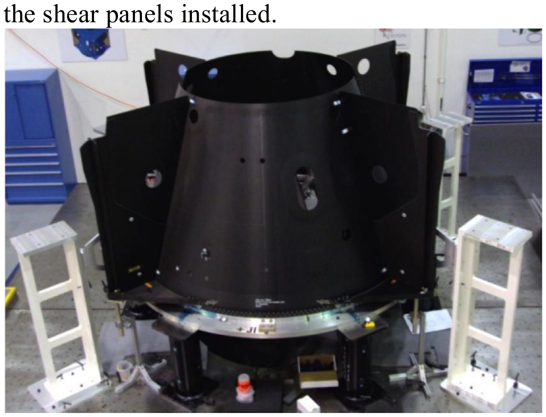
5. Spacecraft

The spacecraft bus is the last hardware element in the development flow for JWST. The JWST program passed the spacecraft Critical Design Review (CDR) in January 2014. In addition, construction of the main spacecraft bus structure has also begun. The JWST spacecraft bus is built around a cone that serves as the main load bearing structure for the observatory. In Figure 8, we show the spacecraft cone after the fitting of its shear panels that provide the support for the instrument panels mounting flight avionics. During the next phase of integration, the spacecraft bus will be populated with major sub-systems such as the propulsion system.

6. Summary

The JWST program has fully transitioned to the integration and test phase of the program. During 2014, the Spacecraft CDR was completed and construction of the spacecraft bus was initiated. In the coming year, 2015, GSFC will take delivery of the flight PMBA and integration of the telescope will begin. This will be followed by integration of telescope and instruments in 2016, ready for the cryo-optical test of the telescope and instruments at JSC, scheduled for 2017. Following this test, the three major elements, OTE, sunshield and spacecraft are integrated and undergo environmental and deployment testing. Launch is currently scheduled for late 2018.

Figure 8: The JWST spacecraft bus structure is under construction. Shown here is the spacecraft cone, with the shear panels installed.



7. References

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8. Acknowledgements

The JWST system is a collaborative effort involving NASA, ESA, CSA, the Astronomy community and numerous principal investigators. The Observatory benefits from many contributions including NASA GSFC, Northrop Grumman, Ball Aerospace, Alliant Techsystems, ITT Exelis, and Nexolve.